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INTERSPIRO DIVATOR MK II AND DP2 EVALUATION (UNMANNED)

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CONTENTS

	<u>Page No.</u>
Form DD1473.....	i
Contents.....	ii
Tables	iv
Figures	v
Introduction	1
Methods	1
DP2 Surface-supplied Evaluation (Nonfreezing Water)	1
Scenario 1, RE	1
Scenario 2, Free-flow Evaluation	2
Interspiro Divator MK II Scuba Evaluation (Nonfreezing Water)	2
Scenario 3, RE	2
DP2 Surface-supplied Evaluation (Freezing Water).....	3
Scenario 4, RE	3
Scenario 5, Freezing Water Evaluation, 198 fsw	3
Interspiro Divator MK II Scuba Evaluation (Freezing Water).....	4
Scenario 6, RE	4
Scenario 7, Freezing Water Evaluation, 198 fsw	5
Scenario 8, Freezing Water Evaluation, 130 fsw	5
Results	7
DP2 Surface-supplied Evaluation (Nonfreezing Water)	8
Scenario 1, RE	8
Scenario 2, Free-flow Evaluation	12
Interspiro Divator MK II Scuba Evaluation (Nonfreezing Water)	13
Scenario 3, RE	13
DP2 Surface-supplied Evaluation (Freezing Water).....	18
Scenario 4, RE	18
Scenario 5, Freezing Water Evaluation, 198 fsw	21
Interspiro Divator MK II Scuba Evaluation (Freezing Water).....	22
Scenario 6, RE	22
Scenario 7, Freezing Water Evaluation, 198 fsw	25

Scenario 8, Freezing Water Evaluation, 130 fsw	25
Conclusions	26
RE Evaluations	26
DP2 Free-flow Evaluation	27
Freeze-up Evaluations	27
Equipment Discussion	27
Recommendations	29
References.....	30

Appendices

Interspiro DP2 Test Setup Diagram	A-1
Interspiro Divator MK II Scuba Test Setup Diagram.....	A-2

Tables

1 Breathing simulator standard settings	6
2 DP2 RE with positive-pressure FFM, 1500 psig supply, 38 °F water	8
3 DP2 RE with positive-pressure FFM, 800 psig supply, 38 °F water ..	9
4 DP2 RE with nonpositive-pressure FFM, 1500 psig supply, 38 °F water	10
5 DP2 RE with nonpositive-pressure FFM, 800 psig supply, 38 °F water	11
6 DP2 RE with one FFM free flowing	13
7 Divator MK II scuba RE with positive-pressure FFM, 1500 psig supply, 38 °F water.....	13
8 Divator MK II scuba RE with positive-pressure FFM, 800 / 500 psig supply, 38 °F water	15
9 Divator MK II scuba RE with nonpositive-pressure FFM, 1500 psig supply, 38 °F water	16
10 Divator MK II scuba RE with nonpositive-pressure FFM, 500 psig supply, 38 °F water	17
11 DP2 RE with positive-pressure FFM, 1500 psig supply, 29 °F water	19
12 DP2 RE with positive-pressure FFM, 800 psig supply, 29 °F water ..	20
13 DP2 RE with nonpositive-pressure FFM, 1500 psig supply, 29 °F water	20
14 DP2 RE with nonpositive-pressure FFM, 800 psig supply, 29 °F water	21
15 Divator MK II scuba RE with positive-pressure FFM, 1500 psig supply, 29 °F water	22
16 Divator MK II scuba RE with positive-pressure FFM, 500 psig supply, 29 °F water	23
17 Divator MK II scuba RE with nonpositive-pressure FFM, 1500 psig supply, 29 °F water	24
18 Divator MK II scuba RE with nonpositive-pressure FFM, 500 psig supply, 29 °F water	25
19 RE evaluation results summary	26

Figures

1 Depth profile used for Scenarios 5 and 7 freeze-up evaluations	4
2 Depth profile used for Scenario 8 freeze-up evaluation	6
3 DP2 RE with positive-pressure FFM, 1500 psig supply, 38 °F water	9
4 DP2 RE with positive-pressure FFM, 800 psig supply, 38 °F water ..	10
5 DP2 RE with nonpositive-pressure FFM, 1500 psig supply, 38 °F water	11
6 DP2 RE with nonpositive-pressure FFM, 800 psig supply, 38 °F water	12
7 Divator MK II scuba RE with positive-pressure FFM, 1500 psig supply, 38 °F water.....	14
8 Divator MK II scuba RE with positive-pressure FFM, 800 / 500 psig supply, 38 °F water	15
9 Divator MK II scuba RE with nonpositive-pressure FFM, 1500 psig supply, 38 °F water	17
10 Divator MK II scuba RE with nonpositive-pressure FFM, 500 psig supply, 38 °F water	18
11 DP2 RE with positive-pressure FFM, 1500 psig supply, 29 °F water	19
12 DP2 RE with nonpositive-pressure FFM, 1500 psig supply, 29 °F water	21
13 Divator MK II scuba RE with positive-pressure FFM, 1500 psig supply, 29 °F water	23
14 Divator MK II scuba RE with nonpositive-pressure FFM, 1500 psig supply, 29 °F water	24
15 Interspiro high-pressure cylinder gauge showing flooding	27
16 Interspiro Spirolite high-pressure cylinder showing salt leeching	28
17 Close-up of Interspiro Spirolite high-pressure cylinder showing salt leeching.....	29

INTRODUCTION

Tasked to test and evaluate commercially available diving equipment to determine its suitability for Navy use,¹ Navy Experimental Diving Unit (NEDU) evaluated the Interspiro DP2 to determine whether this underwater breathing apparatus (UBA) was safe for manned evaluation in the NEDU test pool and Ocean Simulation Facility (OSF). Previous resistive effort (RE) evaluations were performed with the Divator positive-pressure full face mask (FFM) at a breathing gas supply pressure of 1500 psig in 38 ± 2 °F (3.3 ± 1.1 °C) fresh water. Results of this evaluation (unmanned) were detailed in NEDU Technical Report 06-05.² The U.S. Naval Sea Systems Command then tasked NEDU to further evaluate the Interspiro Divator MK II and DP2 UBAs for possible inclusion among equipment to be listed as Authorized for Navy Use (ANU).³ Annexes C and D of NEDU Test Plan 05-35 describe the additional unmanned tests conducted as part of this further evaluation.⁴ These additional tests included nonfreezing and freezing water RE evaluations for the positive-pressure and nonpositive-pressure FFMs in both surface-supplied and scuba modes and at high and low breathing gas supply pressures.

Unmanned evaluations were performed in the Bravo hyperbaric chamber of NEDU's Experimental Diving Facility (EDF). Schematics showing the Interspiro DP2 and Divator MK II UBA test setups are shown in Appendices A-1 and A-2 of this report.

METHODS

DP2 Surface-Supplied Evaluation (Nonfreezing Water)

Scenario 1:

These tests used Divator MK II positive-pressure and nonpositive-pressure FFMs to evaluate the RE of the DP2 surface-supplied system with a 1500 and 800 psig breathing gas supply.

The Scenario 1 evaluation was made under the following conditions:

- High-pressure (HP) breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- One Interspiro DP2 console was used.
- In simulating one diver at a time, investigators used five Interspiro Divator positive-pressure and five nonpositive-pressure FFMs.
- Five surface-supply umbilicals with integral high-pressure regulators were used.
- The tank was filled with tap water, and the temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).
- Test depths ranged in 33-foot increments from 0 to 198 feet of seawater (fsw) (10.1 meters of seawater [msw]).

- RE was evaluated at 22.5, 40.0, 62.5, 75.0, and 90.0 L/min respiratory minute volume (RMV).

Scenario 2 Free-flow Evaluation:

This test determined whether free flow from one diver's mask would negatively affect the gas supply of a second diver supplied from the same DP2 console. This scenario was conducted once during chamber descent with a 1500 psig and once during chamber ascent with an 800 psig breathing gas supply pressure.

Scenario 2 evaluations were made under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- One Interspiro DP2 console was used during free-flow evaluation.
- One Divator positive-pressure FFM was set to free flow while the other Divator FFM was breathed with the RE evaluated.
- Test depths ranged in 33-foot increments from 0 to 198 fsw.
- RE was evaluated at 62.5 L/min RMV.
- The ark was filled with tap water, and the temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

One FFM was placed on a mannequin head and breathed with the Reimers breathing simulator; the second FFM was allowed to free flow, as the FFM's positive-pressure lever was moved away from the second-stage regulator body. This second FFM was not put on a mannequin head; therefore, with the positive-pressure lever positioned away from the second-stage regulator body, free flow resulted.

Interspiro Divator MK II Scuba Mode RE Evaluation (Nonfreezing Water)

Scenario 3:

RE evaluations were performed for the Divator MK II in the scuba mode with 1500 and 500 psig breathing gas supply pressures.

Scuba mode water evaluations were made under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- Five first-stage regulators were evaluated.
- Five Divator positive-pressure and five nonpositive-pressure FFMs were used.
- The ark was filled with tap water, and the temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).
- Test depths ranged in 33-foot increments from 0 to 198 fsw.
- RE was evaluated at 22.5, 40.0, 62.5, 75.0, and 90.0 L/min RMV.

DP2 Surface-supplied Evaluation (Freezing Water)

Scenario 4:

These tests used MK II positive-pressure and nonpositive-pressure FFMs to evaluate the RE of the DP2 surface-supplied system in freezing water.

RE evaluations were made in freezing water under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- One Interspiro DP2 console was used.
- Five surface-supply umbilicals with integral first-stage regulators were evaluated. Each umbilical was evaluated with a Divator positive-pressure and a nonpositive-pressure FFM, a total of five positive- and five nonpositive-pressure FFMs.
- The ark was filled with salt water, and the temperature was maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).
- Test depths ranged from 0 to 198 fsw in 33-foot increments with a breathing gas supply of 1500 psig for RMVs of 22.5, 40.0, 62.5, 75.0, and 90.0 L/min.
- Additional evaluations at depths of 198 and 132 fsw were made with a breathing gas supply of 800 psig and an RMV of 62.5 L/min.
- Investigators evaluated one simulated diver breathing one FFM.

Scenario 5:

Ten surface-supplied dives were made to evaluate the UBAs' susceptibility to freeze-up. RE data was collected at 10-minute intervals, and breathing was briefly stopped to inspect for sustained free flow. After 30 minutes the chamber was surfaced, and an inspection of the UBA was made to ascertain whether free flow had resulted. Figure 1 presents the freeze-up diving profile.

Scenario 5 evaluated dives for freeze-up under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- One Interspiro DP2 console was used.
- Five Divator MK II positive- and five nonpositive-pressure FFMs were used.
- Five surface-supply umbilicals with integral first-stage regulators were used. Each umbilical was dived once with a positive- and once with a nonpositive-pressure FFM.
- The ark was filled with salt water, and the temperature was maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).
- The breathing simulator was set at 62.5 L/min RMV.
- The depth was 198 fsw.

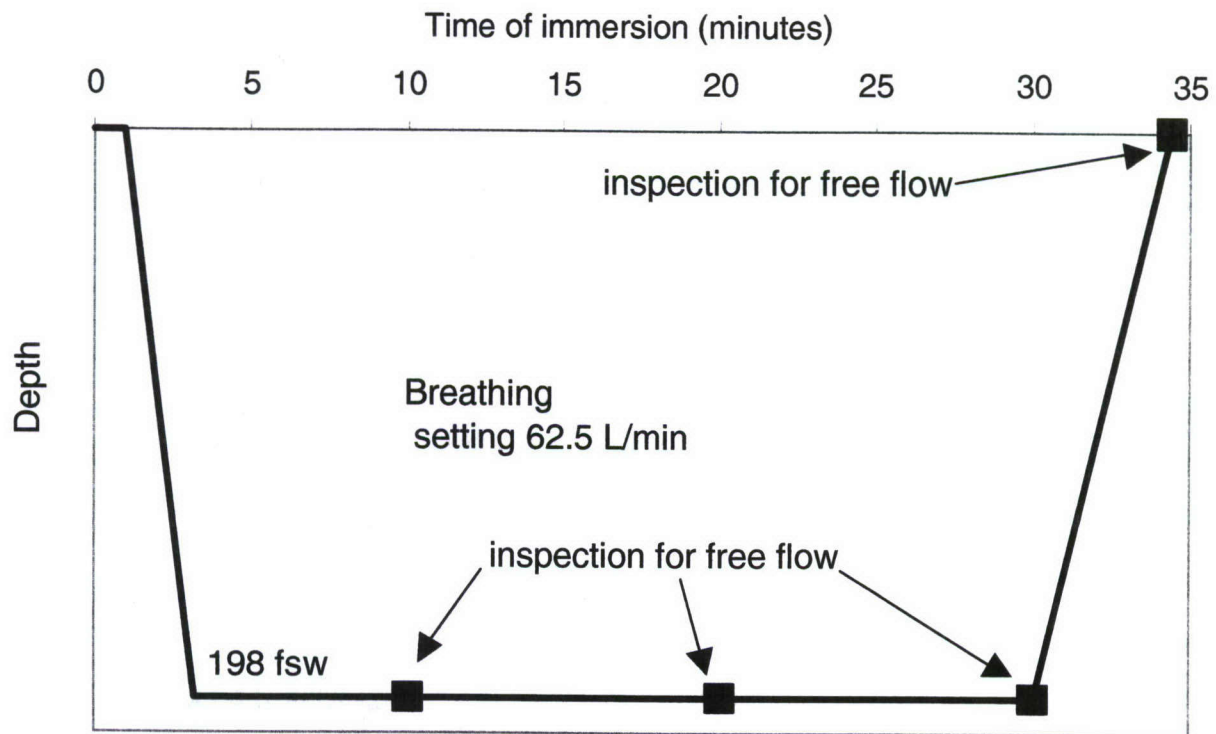


Figure 1. Depth profile used for freeze-up evaluations in Scenarios 5 and 7.

Interspiro Divator MK II Scuba Mode Evaluation (Freezing Water)

Scenario 6:

The Divator MK II scuba was evaluated for RE with 1500 psig breathing gas supply pressures.

Scenario 6 made scuba mode freezing-water evaluations under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- Five first-stage regulators were evaluated.
- Five Divator positive- and five nonpositive-pressure FFMs were used.
- The ark was filled with tap water, and the temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).
- Test depths ranged from 0 to 198 fsw in 33-foot increments.
- RE was evaluated at 22.5, 40.0, 62.5, 75.0, and 90.0 L/min RMV.
- Additional evaluations at depths of 198 and 132 fsw were made with a breathing gas supply of 500 psig and an RMV of 62.5 L/min.

Scenario 7:

These tests used positive- and nonpositive-pressure FFMs to evaluate the freezing-water RE of the Divator MK II scuba system. Figure 1 presents the freeze-up diving profile.

Scenario 7 made scuba mode freezing-water evaluations under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- Five Divator positive- and five nonpositive-pressure FFMs were used.
- The ark was filled with salt water, and the temperature was maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).
- The test depth was 198 fsw (60.7 msw).
- RE was evaluated at 62.5 L/min RMV.

Scenario 8:

Per NEDU Test Plan 05-35, if any UBA failed to successfully complete the 198 fsw freezing-water dive profile by exhibiting sustained free flow, an additional 130 fsw (39.8 msw) dive profile was conducted. RE data was collected, and the breathing was briefly stopped to inspect for sustained free flow about one minute before leaving the bottom. If free flow occurred, UBA immersion time was recorded. After 20 minutes of immersion, the chamber was traveled upward. Five-minute decompression stops were made at 40, 30, 20, and 10 fsw (12.3, 9.2, 6.1, and 3 msw). Figure 2 presents the 130 fsw freezing-water dive profile.

Scenario 8 made scuba mode freezing-water evaluations under the following conditions:

- HP breathing air was supplied from the EDF bottle field through the breathing air regulator of the Bravo chamber console.
- Five Divator positive- and five nonpositive-pressure FFMs were used.
- The ark was filled with salt water, and the temperature was maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).
- The test depth was 130 fsw (39.8 msw).
- RE was evaluated at 50.0 L/min RMV.

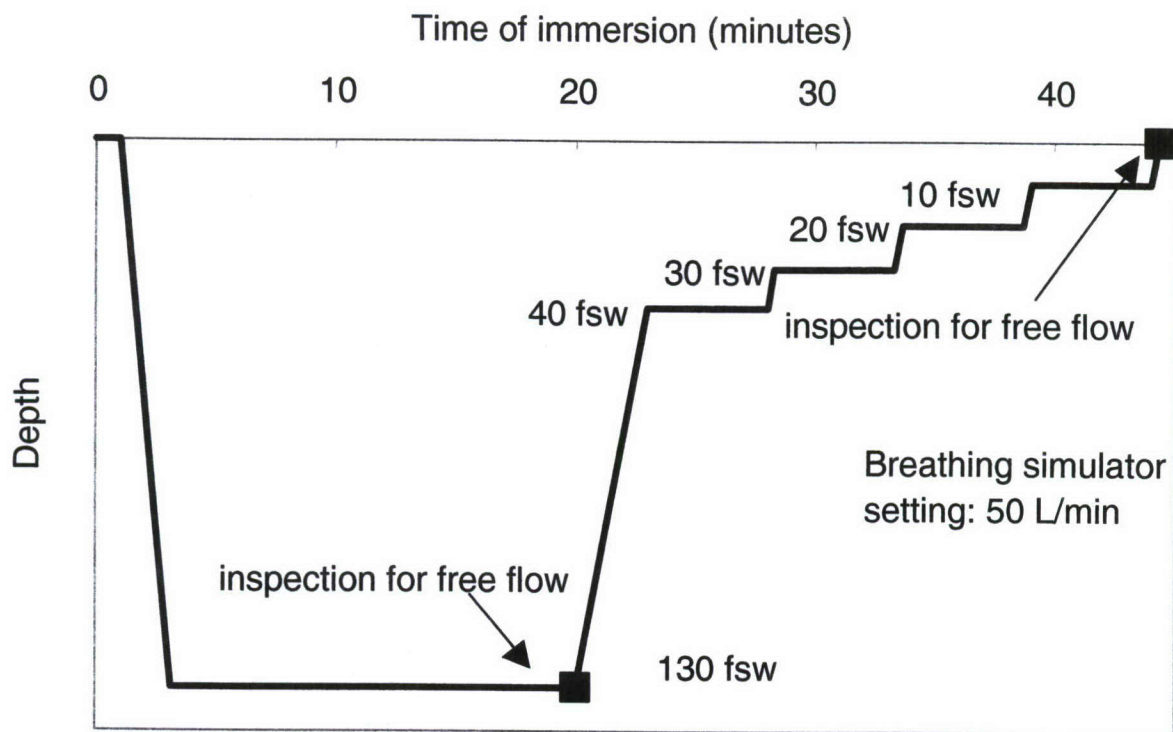


Figure 2. Depth profile used for the Scenario 8 freeze-up evaluation.

Breathing simulator settings were those in Table 1 for all RE evaluations.

Table 1.

Breathing simulator standard settings

Frequency (Breaths per minute)	Volume (Liters)	RMV (L/min)	Diver Work Rate
15	1.5	22.5	Light
20	2.0	40.0	Moderately Heavy
25	2.5	62.5	Heavy
30	2.5	75.0	Severe
30	3.0	90.0	Extreme

At each depth and RMV combination, 10 pressure-volume (P-V) loops were recorded. The RE, a volume-averaged pressure, was reported in kPa for each ensemble average of the 10 P-V loops generated at each depth and RMV.

The RE performance goal for Category 1 demand UBAs is 1.37 kPa for RMVs up to 62.5 L/min. For Category 2 umbilical-supplied demand UBAs, the goal is 1.76 kPa.⁵

NEDU Technical Manual 01-94 provides no established RE goals for RMVs greater than 62.5 L/min.

A three-question process was used to determine whether an RE met the UBA performance goal:

Question 1: Was the RE \leq the Technical Manual 01-94 goal (1.37 kPa for Category 1 UBA; 1.76 kPa for Category 2 UBA at 62.5 L/min RMV)? If yes, the goal was met. If not, Question 2 was asked.

Question 2: Was the RE statistically $>$ the goal when a one-tailed, one-sample t-test was applied? If yes, the goal was not met. If the RE was not statistically $>$ the goal, then Question 3 was asked.

Question 3: Was the RE standard deviation (SD) value acceptable? If yes, the goal was met. If not, the goal was not met.

Technical Manual 01-94 does not specify a maximum allowable SD for Category 2 UBA RE values. It does, however, specify an allowable SD (0.2 kPa) for RE values for Category 1 demand UBAs with the RE goal of 1.37 kPa.⁵ Discussions with Dr. Dan E. Warkander indicate that it is reasonable to multiply the specified Category 1 SD goal by the ratio of the Category 1 and Category 2 RE goals to approximate an acceptable SD for Category 2 UBAs:

Category 2 SD goal \approx (Category 2 RE goal / Category 1 RE goal) \times 0.2

(Equation 1)

Category 2 SD goal \approx (1.76 / 1.37) \times 0.2

Category 2 SD goal \approx 0.26 kPa

RESULTS

Results of RE data analysis for the Interspiro DP2 and Divator MK II scuba evaluations are summarized in Tables 2–18 and in Figures 3–14.

For surface-supplied RE results (Tables 2–5 and 11–14), the following logic applies:

- (A) The actual RE value $>$ 1.76 kPa; however, the t-test indicates that the value is not statistically $>$ 1.76 kPa. Therefore, the RE goal is met.
- (B) The actual value $>$ 1.76 kPa, and the t-test indicates that the value is statistically $>$ 1.76 kPa. Therefore, the RE goal is not met.
- (C) The SD $>$ 0.26 kPa; therefore, the RE goal is not met.
- (XP) The measured peak pressure $>$ the test termination criterion of 7 kPa.

For scuba mode RE results (Tables 7–10 and 15–18), the following logic applies:

- (A) The actual RE value > 1.37 kPa; however, the t-test indicates that the value is not statistically > 1.37 kPa. Therefore, the RE goal is met.
- (B) The actual value > 1.37 kPa, and the t-test indicates that the value is statistically > 1.37 kPa. Therefore, the RE goal is not met.
- (C) The SD > 0.20 kPa; therefore, the RE goal is not met.
- (XP) The measured peak pressure > the test termination criterion of 7 kPa.

DP 2 Surface-supplied Evaluation (Nonfreezing Water)

Scenario 1:

Table 2 and Figure 3 present Scenario 1 average RE results for the Interspiro DP2 with a positive-pressure FFM and 1500 psig supply pressure in 38 °F fresh water.

Table 2.

DP2 surface-supplied positive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water and its temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 Fsw
22.5	0.41	0.49	0.54	0.59	0.64	0.68	0.71
40.0	0.42	0.55	0.65	0.72	0.77	0.82	0.88
62.5	0.51	0.67	0.81	0.94	1.08	1.22	1.44
75.0	0.57	0.76	0.92	1.14	1.31	1.90 (C)	(XP)
90.0	0.64	0.87	1.13	1.42	1.98*	(XP)	(XP)

*At 132 fsw and 90 L/min RMV the RE is based upon four samples (1.99, 2.30, 1.88, and 1.74 kPa). The fifth data point was "XP."

INTERSPIRO DP2, POSITIVE-PRESSURE FFM

(Air: 60-meter Umbilical, 1500 psig Supply, 38 °F)

AVERAGE RESISTIVE EFFORT

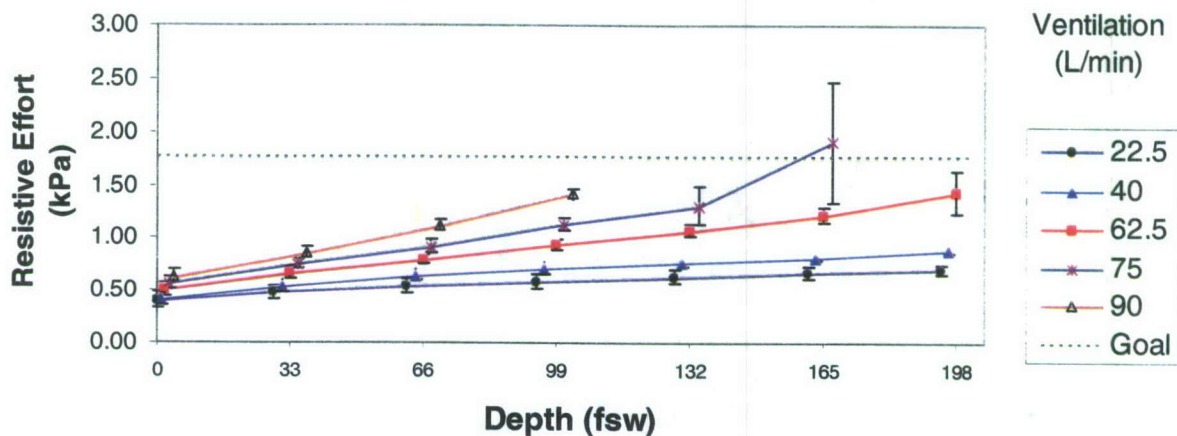


Figure 3. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 198 fsw or for 90 L/min at 132, 165, and 198 fsw. All data points represent five samples.

Table 3 and Figure 4 present Scenario 1 average RE results for the Interspiro DP2 with a positive-pressure FFM and 800 psig supply pressure in 38 °F fresh water.

Table 3.

DP2 surface-supplied positive-pressure FFM average RE results with air as the breathing medium and an 800 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.39	0.48	0.54	0.58	0.63	0.65	0.71
40.0	0.44	0.57	0.66	0.72	0.77	0.82	0.89
62.5	0.52	0.68	0.80	0.92	1.08	1.24	1.45
75.0	0.59	0.76	0.93	1.13	1.22	1.92 (B), (C)	(XP)
90.0	0.65	0.88	1.13	1.44	1.80 (A)	(XP)	(XP)

INTERSPIRO DP2, POSITIVE-PRESSURE FFM

(Air: 60-meter Umbilical, 800 psig Supply, 38 °F)

AVERAGE RESISTIVE EFFORT

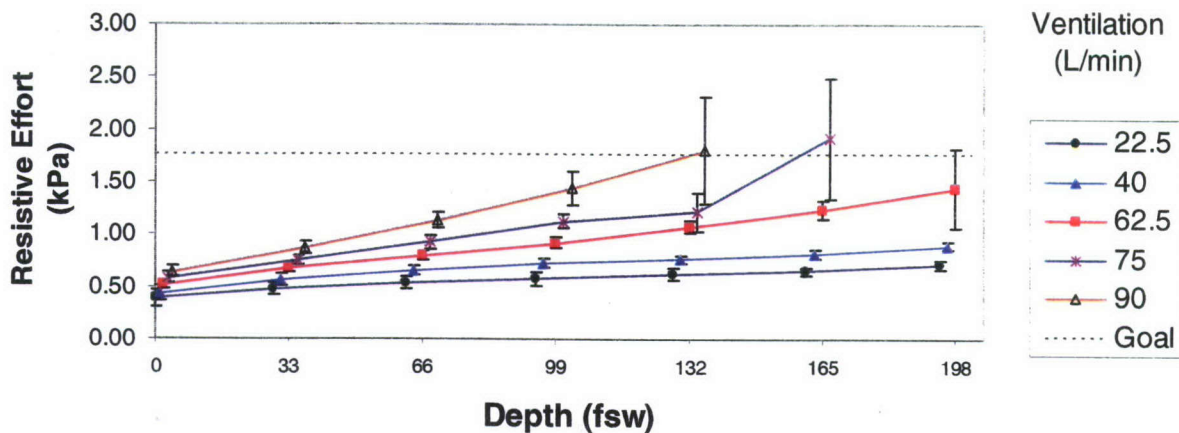


Figure 4. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 198 fsw or for 90 L/min at 165 and 198 fsw. All data points represent five samples.

Table 4 and Figure 5 present Scenario 1 average RE results for the Interspiro DP2 with a nonpositive-pressure FFM and 1500 psig supply pressure in 38 °F fresh water.

Table 4.

DP2 surface-supplied nonpositive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.55	0.64	0.69	0.72	0.77	0.81	0.85
40.0	0.58	0.71	0.79	0.87	0.94	1.00	1.09
62.5	0.67	0.85	1.00	1.15	1.33	1.49	1.78 (A)
75.0	0.73	0.95	1.16	1.39	1.65	2.21 (B), (C)	3.29*
90.0	0.81	1.09	1.39	1.75	2.75 (B), (C)	(XP)	(XP)

*At 198 fsw and 75 L/min RMV, the RE is based upon three samples.

INTERSPIRO DP2, NONPOSITIVE-PRESSURE FFM

(Air: 60-meter Umbilical, 1500 psig Supply, 38 °F)

AVERAGE RESISTIVE EFFORT

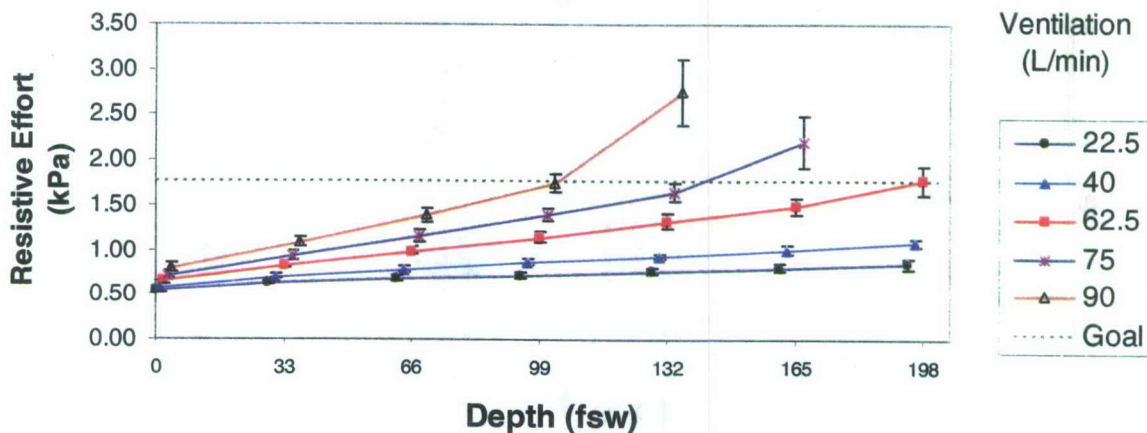


Figure 5. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 198 fsw or for 90 L/min at 165 and 198 fsw. All data points represent five samples.

Table 5 and Figure 6 present Scenario 1 average RE results for the Interspiro DP2 with a nonpositive-pressure FFM and 800 psig supply pressure in 38 °F fresh water.

Table 5.

DP2 surface-supplied nonpositive-pressure FFM average RE results with air as the breathing medium and an 800 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.56	0.63	0.69	0.73	0.78	0.81	0.86
40.0	0.61	0.72	0.80	0.86	0.92	1.00	1.09
62.5	0.68	0.84	0.99	1.16	1.34	1.52	1.9 (A)
75.0	0.74	0.95	1.16	1.41	1.69	2.4 (B), (C)	(XP)
90.0	0.82	1.11	1.43	1.81 (A)	2.90 (B), (C)	(XP)	(XP)

INTERSPIRO DP2, NONPOSITIVE-PRESSURE FFM

(Air: 60-meter Umbilical, 800 psig Supply, 38 °F)

AVERAGE RESISTIVE EFFORT

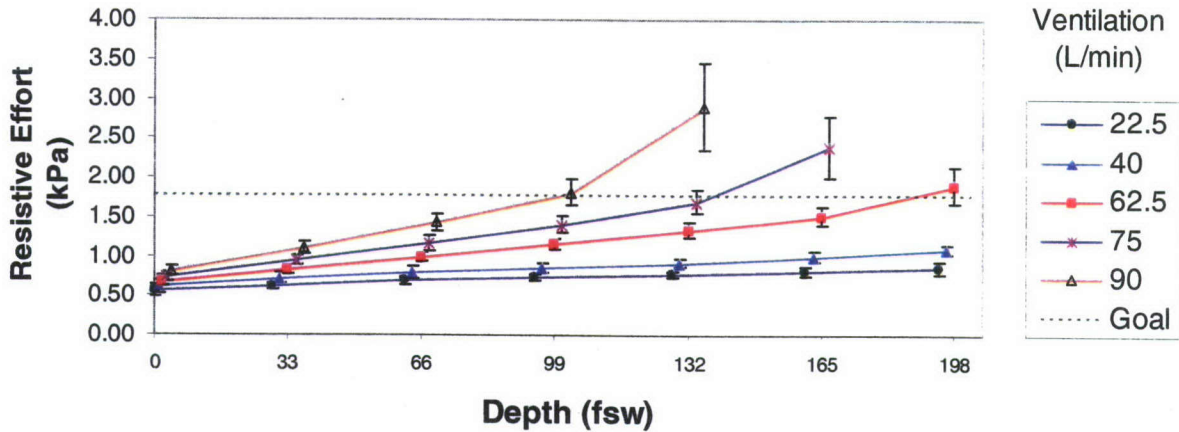


Figure 6. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 198 fsw or for 90 L/min at 165 and 198 fsw. All data points represent five samples.

Scenario 2 Free-Flow Evaluation:

Table 6 presents Scenario 2 RE results for one Divator MK II positive-pressure FFM while a second FFM was allowed to free flow.

Table 6.

RE results for the DP2 surface-supplied positive-pressure FFM with a second FFM free flowing. Air was the breathing medium. Breathing gas supply pressures were 1500 and 800 psig. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min) — PSIG	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
62.5 — 1500	0.59	0.71	0.86	1.03	1.19	1.36	1.95
62.5 — 800	0.55	0.70	0.84	1.00	(XP)	(XP)	(XP)

Interspiro Divator MK II Scuba Mode Evaluation (Nonfreezing Water)

Scenario 3:

Table 7 and Figure 7 present Scenario 3 average RE results for the Divator MK II scuba with a positive-pressure FFM and 1500 psig supply pressure in 38 °F fresh water.

Table 7.

Divator MK II scuba mode positive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.51	0.54	0.61	0.65	0.68	0.72	0.73
40.0	0.55	0.61	0.74	0.77	0.84	1.04	0.96
62.5	0.61	0.77	0.90	1.05	1.19	1.40 (A)	2.10 (B), (C)
75.0	0.69	0.88	1.04	1.26	1.62 (A), (C)	2.69** (B), (C)	(XP)
90.0	0.75	1.01	1.26	1.75 (B), (C)	3.33*	(XP)	(XP)

*At 132 fsw and 90 L/min RMV, the RE is based upon two samples.

**At 165 fsw and 75 L/min RMV, the RE is based upon four samples.

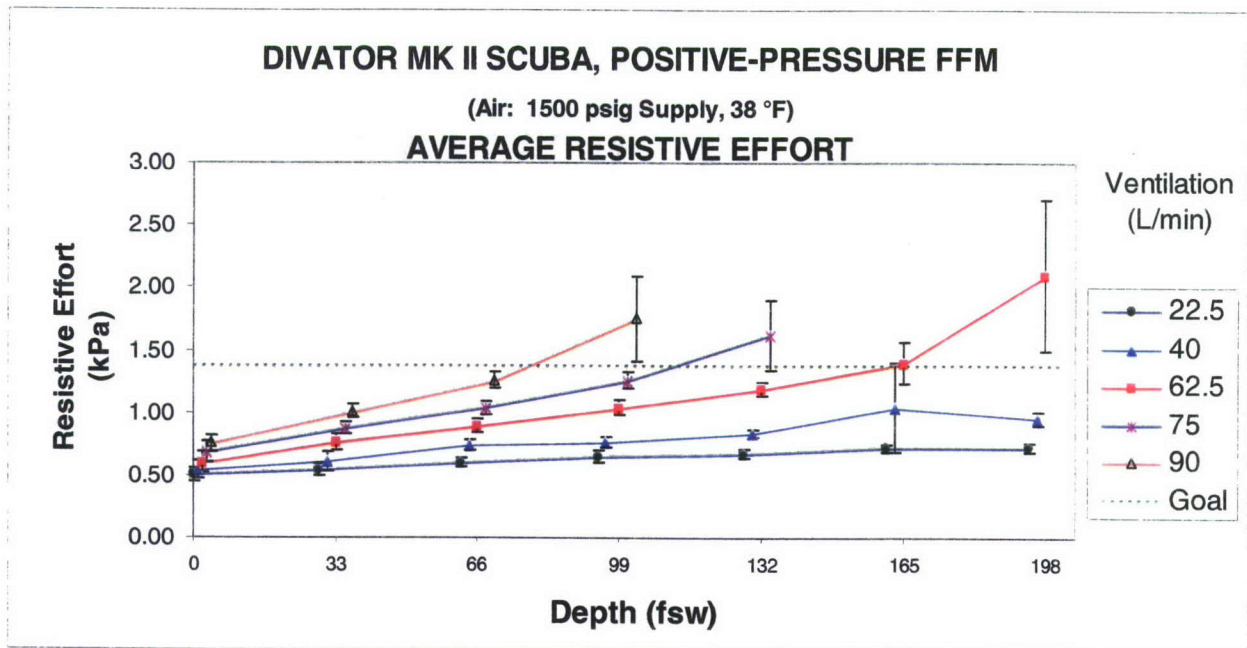


Figure 7. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.37 kPa) for Category 1 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 165 and 198 fsw, or for 90 L/min at 132, 165, and 198 fsw. All data points represent five samples.

Table 8 and Figure 8 present Scenario 3 average RE results for the Divator MK II scuba with a positive-pressure FFM. Data represent the average of two RE evaluations with an 800 psig supply pressure (DP2 minimum surface-supply pressure was erroneously used) and three RE evaluations with a 500 psig supply pressure.

Table 8.

Divator MK II scuba mode positive-pressure FFM average RE results with air as the breathing medium and a mix of 800 and 500 psig supply pressures. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at $38 \pm 2^\circ\text{F}$ ($3.3 \pm 1.1^\circ\text{C}$).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.48	0.56	0.60	0.64	0.66	0.71	0.72
40.0	0.53	0.64	0.71	0.77	0.83	0.90	0.96
62.5	0.63	0.77	0.89	1.04	1.21	1.71 (B), (C)	2.25*
75.0	0.68	0.85	1.05	1.28	2.05 (B), (C)	3.28*	(XP)
90.0	0.75	0.98	1.26	2.21 (B), (C)	(XP)	(XP)	(XP)

*At 165 fsw and 75 L/min RMV and at 198 fsw and 62.5 L/min RMV, the REs are based upon two samples.

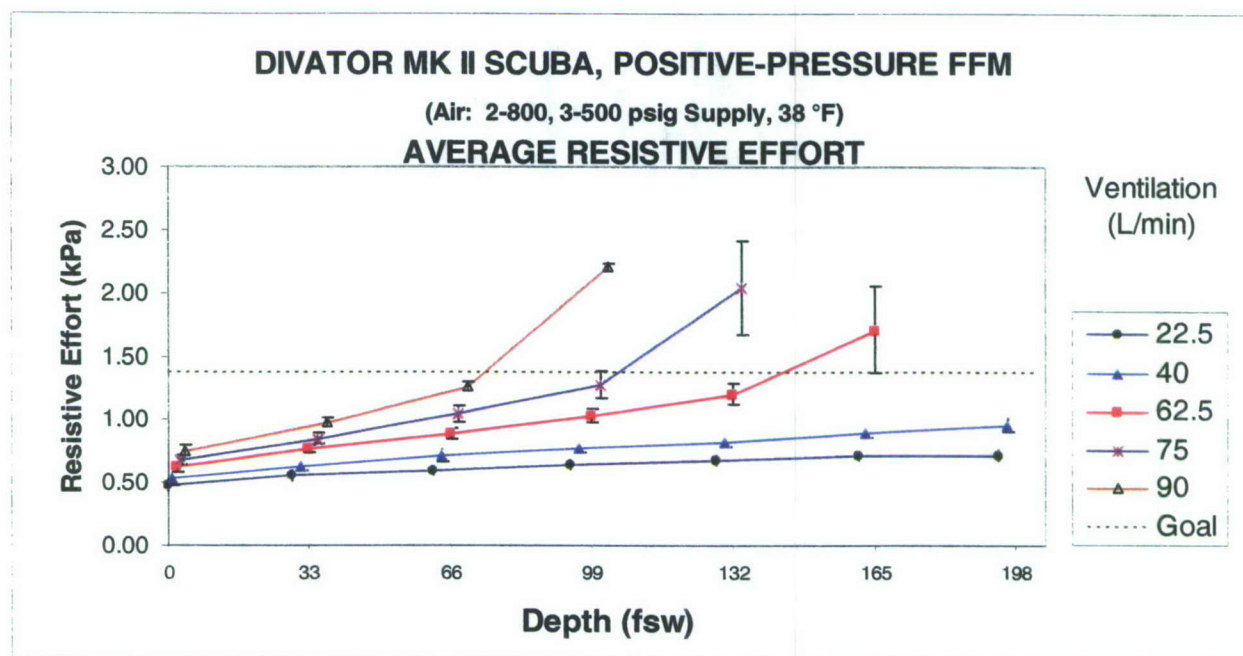


Figure 8. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.37 kPa) for Category 1 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 165 and 198 fsw, or for 90 L/min at 132, 165, and 198 fsw. Data points represent a total of five samples.

Table 9 and Figure 9 present Scenario 3 average RE evaluation results for the Divator MK II scuba with a nonpositive-pressure FFM and 1500 psig supply pressure in 38 °F fresh water.

Table 9.

Divator MK II scuba mode nonpositive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.62	0.67	0.71	0.75	0.80	0.83	0.83
40.0	0.66	0.76	0.85	0.91	0.99	1.07	1.13
62.5	0.74	0.93	1.08	1.23	1.42 (A)	1.70 (B)	2.51 (B)
75.0	0.81	1.02	1.25	1.49 (B)	2.27 (B), (C)	3.35*	(XP)
90.0	0.88	1.18	1.48 (B)	2.25 (B)	(XP)	(XP)	(XP)

*At 165 fsw at 75 L/min RMV, the RE is based upon one sample.

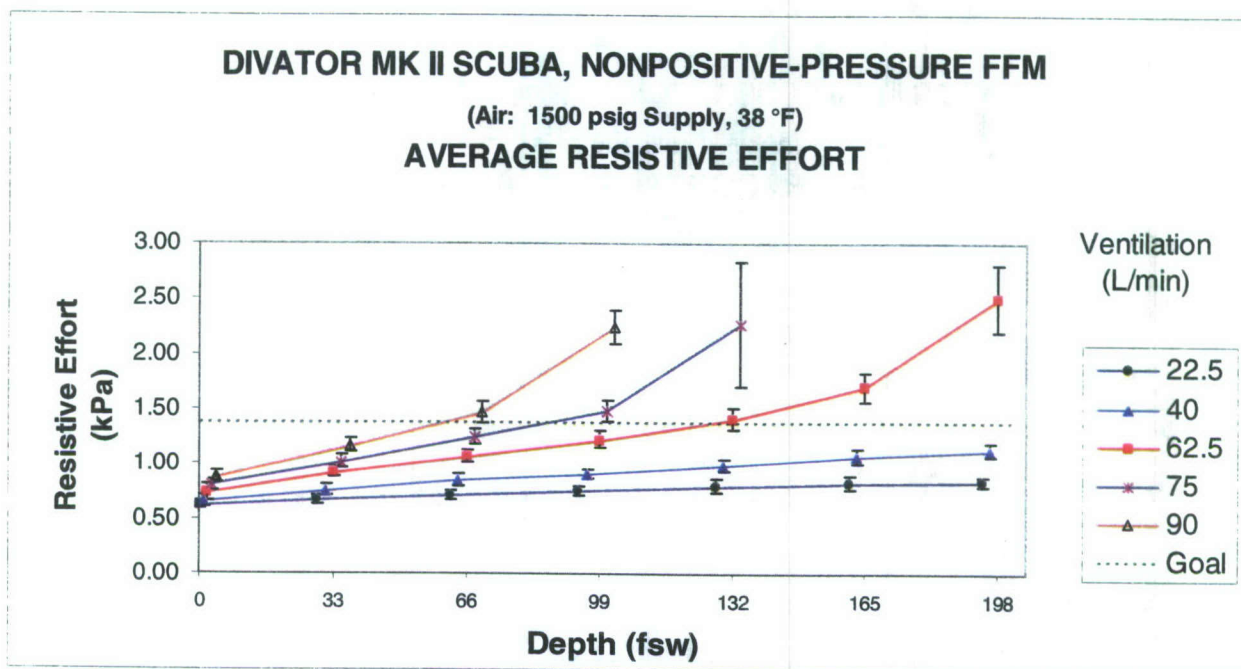


Figure 9. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.37 kPa) for Category 1 UBAs. Because of excessive pressures (measured peak pressures that exceeded the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 165 and 198 fsw, or for 90 L/min at 132, 165, and 198 fsw. All data points represent five samples.

Table 10 and Figure 10 present Scenario 3 average RE results for the Divator MK II scuba with a positive-pressure FFM and 500 psig supply pressure in 38 °F fresh water.

Table 10.

Divator MK II scuba mode nonpositive-pressure FFM average RE results with air as the breathing medium and a 500 psig supply pressure. Values shown are in kPa. The ark was filled with fresh (tap) water with the temperature maintained at 38 ± 2 °F (3.3 ± 1.1 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.61	0.67	0.72	0.76	0.80	0.83	0.84
40.0	0.66	0.74	0.83	0.90	0.98	1.06	1.13
62.5	0.77	0.92	1.06	1.22	1.41 (A)	2.09 (B)	(XP)
75.0	0.82	1.03	1.26	1.51 (B)	2.31 (B)	(XP)	(XP)
90.0	0.91	1.21	1.54 (B)	2.29 (B)	(XP)	(XP)	(XP)

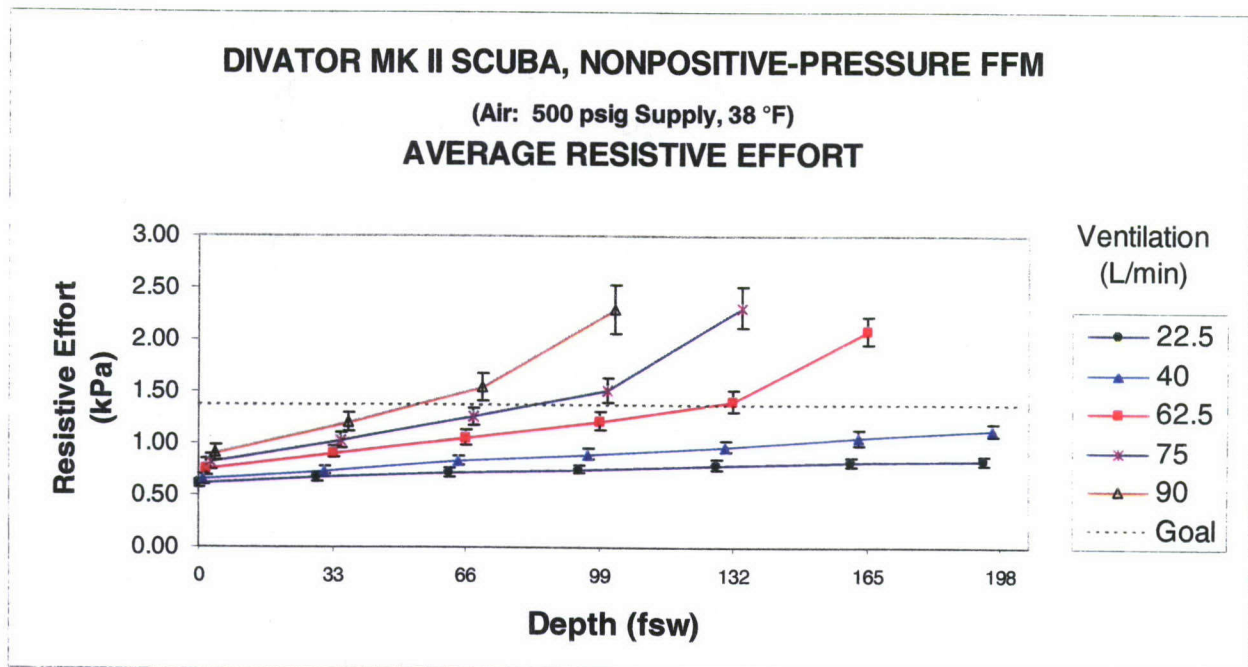


Figure 10. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.37 kPa) for Category 1 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 62.5 L/min at 198 fsw, 75 L/min at 165 and 198 fsw, or 90 L/min at 132, 165, and 198 fsw. All data points represent five samples.

DP 2 Surface-supplied Evaluation (Freezing Water)

Scenario 4:

Table 11 and Figure 11 present Scenario 4 average RE results for the Interspiro DP2 with a positive-pressure FFM and 1500 psig supply pressure in 29 °F salt water.

Table 11.

DP2 surface-supplied positive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at $29 \pm 1^\circ\text{F}$ ($-1.7 \pm 0.6^\circ\text{C}$).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.47	0.54	0.60	0.64	0.68	0.74	0.76
40.0	0.52	0.63	0.73	0.80	0.89	0.96	1.02
62.5	0.64	0.82	0.97	1.06	1.19	1.38	1.82 (A), (C)
75.0	0.74	0.97	1.09	1.29	1.55	2.15* (A), (C)	3.18**
90.0	0.86	1.07	1.36	1.72	2.65* (B)	(XP)	(XP)

*At 132 fsw at 90 L/min and at 165 fsw at 75 L/min RMV, the RE is based upon four samples.

**At 198 fsw at 75 L/min RMV, the RE is based upon two samples.

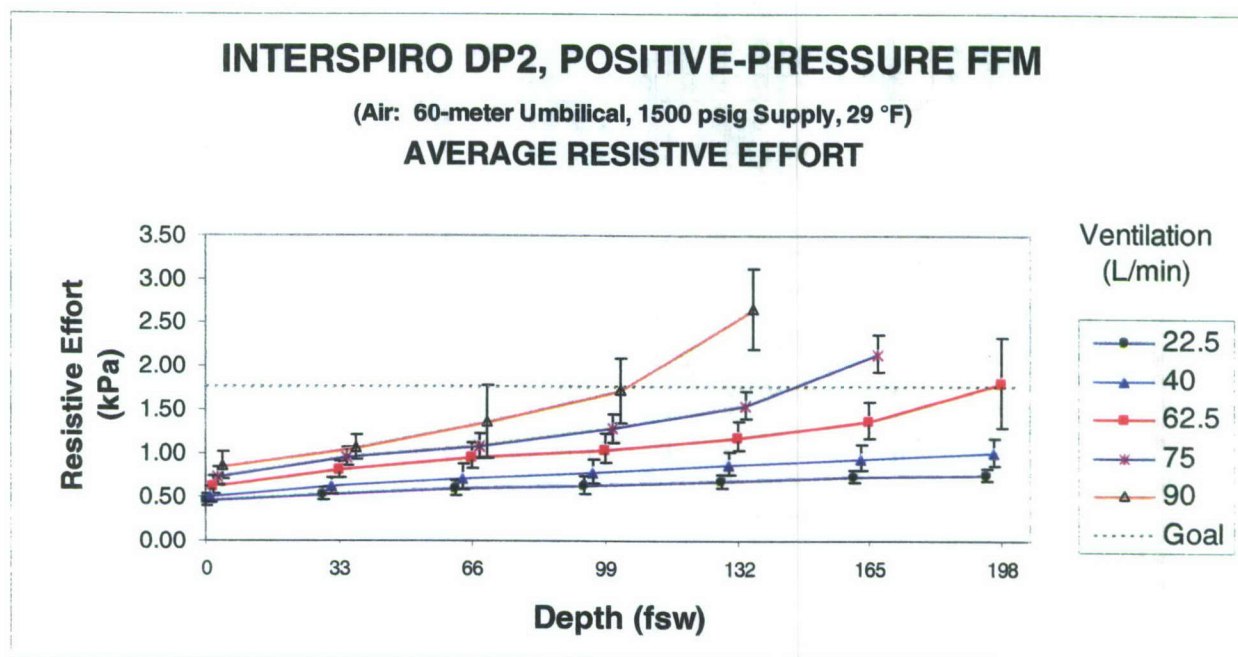


Figure 11. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 198 fsw or for 90 L/min at 165 and 198 fsw. For 75 L/min at 165 fsw and for 90 L/min at 132 fsw, data points represent four samples. All other data points represent five samples.

Table 12 presents Scenario 4 average RE results for the Interspiro DP2 with a positive-pressure FFM and 800 psig supply pressure in 29 °F salt water.

Table 12.

DP2 surface-supplied positive-pressure FFM average RE results with air as the breathing medium and an 800 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).

RMV L/min	132 fsw	198 fsw
62.5	1.14	1.59*

*At 198 fsw and 62.5 L/min RMV, the RE is based upon four samples.

Table 13 and Figure 12 present Scenario 4 average RE results for the Interspiro DP2 with a nonpositive-pressure FFM and 1500 psig supply pressure in 29 °F salt water.

Table 13.

DP2 surface-supplied nonpositive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.64	0.68	0.70	0.76	0.80	0.82	0.85
40.0	0.68	0.74	0.81	0.89	0.95	1.02	1.10
62.5	0.71	0.89	1.06	1.24	1.36	1.56	1.87 (A)
75.0	0.78	0.99	1.25	1.49	1.74	2.44 (B)	(XP)
90.0	0.87	1.16	1.51	1.85 (A)	2.91 (B), (C)	(XP)	(XP)

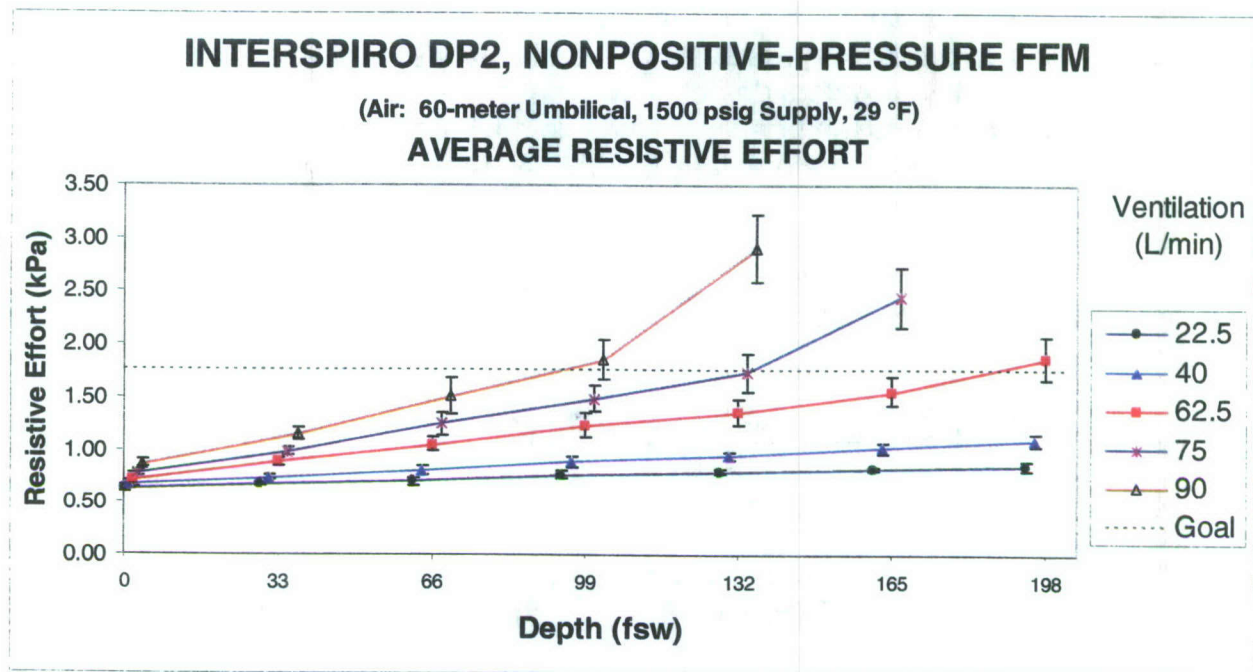


Figure 12. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures (measured peak pressures that exceed the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 198 fsw or for 90 L/min at 165 and 198 fsw. All data points represent five samples.

Table 14 presents Scenario 4 average RE results for the Interspiro DP2 with a nonpositive-pressure FFM and 800 psig supply pressure in 29 °F salt water.

Table 14.

DP2 surface-supplied nonpositive-pressure FFM average RE results with air as the breathing medium and an 800 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).

RMV L/min	132 fsw	198 fsw
62.5	1.36	2.01 (B)

Scenario 5:

The DP2 using the positive-pressure FFM completed four of five freeze-up evaluations without any instances of free flow. One FFM did exhibit a slight trickle of bubbles when the breathing simulator was stopped at the 10- and 20-minute checkpoints; however, no free flow occurred at the 30-minute checkpoint. Upon surfacing, the FFM showed moderate free flow. The average RE at 198 fsw for this umbilical and FFM combination

during this freeze-up evaluation was higher (2.29 kPa) than the average RE for the other four umbilical and positive-pressure FFM combinations (1.76 kPa) that did not exhibit any free flow. Investigators do not know what significance, if any, this higher RE may have had with regard to the free flow. They do not believe that the free flow was evidence of freeze-up, and, therefore, they did not perform a 130 fsw freeze-up dive evaluation.

The DP2 using the nonpositive-pressure FFM completed the 198 fsw freeze-up evaluation without any instances of free flow.

Interspiro Divator MK II Scuba Evaluation (Freezing Water)

Scenario 6:

Table 15 and Figure 13 present Scenario 6 average RE results for the Divator MK II scuba with a positive-pressure FFM and 1500 psig supply pressure in 29 °F salt water.

Table 15.

Divator MK II scuba positive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The tank was filled with salt water with the temperature maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.52	0.58	0.62	0.67	0.71	0.73	0.75
40.0	0.57	0.67	0.73	0.79	0.85	0.91	0.97
62.5	0.67	0.81	0.93	1.07	1.28	1.72* (B), (C)	2.15**
75.0	0.73	0.90	1.09	1.41 (A)	2.65 (B), (C)	(XP)	(XP)
90.0	0.80	1.05	1.43 (A)	2.65* (B), (C)	(XP)	(XP)	(XP)

*At 165 fsw at 62.5 L/min and at 99 fsw at 90 L/min, the RE is based upon four samples.

**At 198 fsw at 62.5 L/min RMV, the RE is based upon two samples.

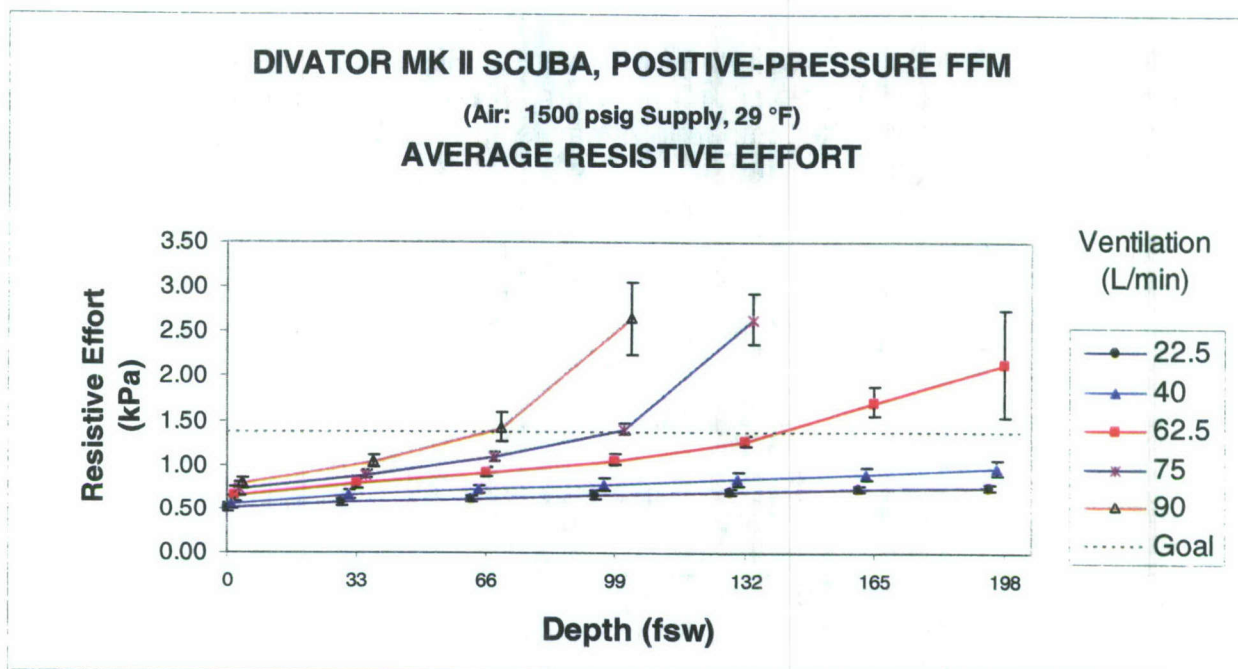


Figure 13. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.37 kPa) for Category 1 UBAs. Because of excessive pressures (measured peak pressures that exceeded the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 165 and 198 fsw, or for 90 L/min at 132, 165, and 198 fsw. For 62.5 L/min at 198 fsw, the data point represents two samples. For 62.5 L/min at 165 fsw and for 90 L/min at 99 fsw, the data points represent four samples. All other data points represent five samples.

Table 16 depicts Scenario 6 average RE evaluation results for the Divator MK II scuba with a positive-pressure FFM and 500 psig supply pressure in 29 °F salt water.

Table 16.

Divator MK II scuba positive-pressure FFM average RE results with air as the breathing medium and a 500 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).

RMV L/min	132 fsw	198 fsw
40.0	Not tested	1.33
62.5	0.98	(XP)

Table 17 and Figure 14 present Scenario 6 average RE results for the Divator MK II with a nonpositive-pressure FFM and 1500 psig supply pressure in 29 °F salt water.

Table 17.

Divator MK II scuba nonpositive-pressure FFM average RE results with air as the breathing medium and a 1500 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at $29 \pm 1^\circ\text{F}$ ($-1.7 \pm 0.6^\circ\text{C}$).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.64	0.67	0.73	0.78	0.81	0.84	0.86
40.0	0.66	0.76	0.86	0.91	0.99	1.06	1.13
62.5	0.77	0.94	1.09	1.26	1.42 (A)	1.75 (B)	2.83* (B)
75.0	0.82	1.02	1.28	1.59 (B)	2.17 (B)	3.59**	(XP)
90.0	0.92	1.21	1.65 (B)	2.61 (B), (C)	(XP)	(XP)	(XP)

* At 198 fsw at 62.5 L/min, the RE is based upon four samples.

** At 165 fsw at 75.0 L/min RMV, the RE is based upon two samples.

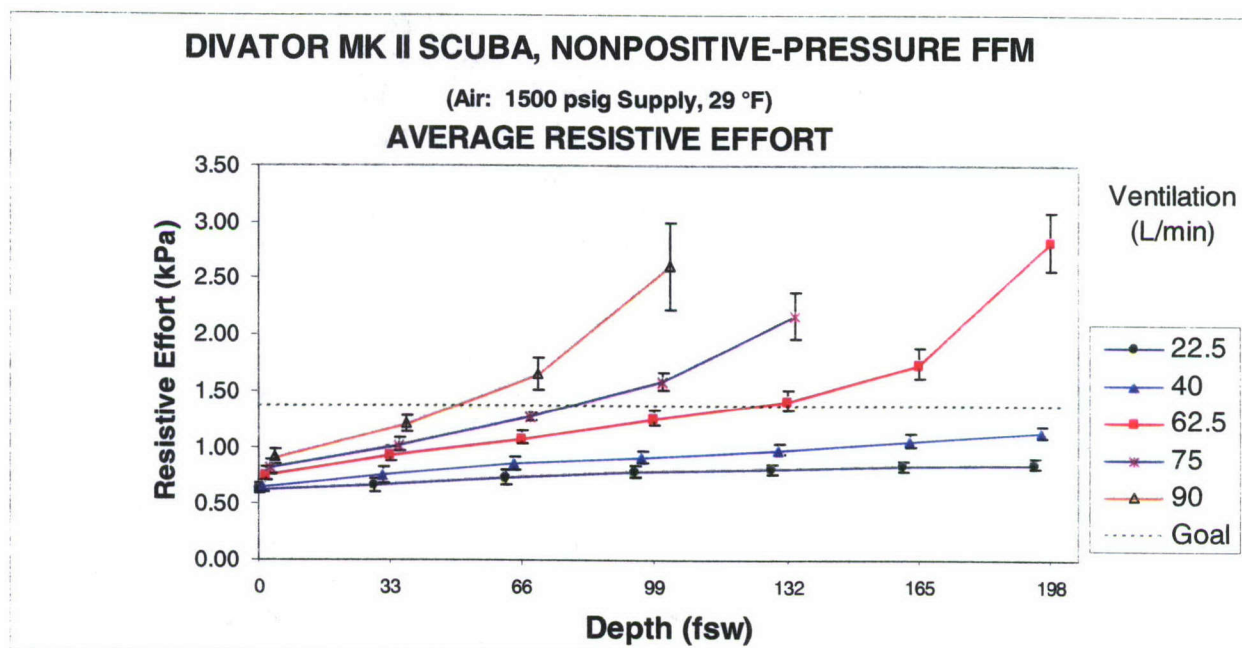


Figure 14. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.37 kPa) for Category 1 UBAs. Because of excessive pressures (measured peak pressures that exceeded the testing termination criterion of 7 kPa), no data points are shown for 75 L/min at 165 and 198 fsw, or for 90 L/min at 132, 165, and 198 fsw. For 62.5 L/min at 198 fsw data, the data points represent four samples. All other data points represent five samples.

Table 18 presents Scenario 6 average RE results for the Divator MK II scuba with a nonpositive-pressure FFM and 500 psig supply pressure in 29 °F salt water.

Table 18.

Divator MK II scuba nonpositive-pressure FFM average RE results with air as the breathing medium and a 500 psig supply pressure. Values shown are in kPa. The ark was filled with salt water with the temperature maintained at 29 ± 1 °F (-1.7 ± 0.6 °C).

RMV L/min	132 fsw	198 fsw
40.0	Not tested	1.10*
62.5	1.44 (A)	(XP)

*At 198 fsw and 40 L/min RMV, the RE is based upon three samples.

Scenario 7:

This freeze-up evaluation (breathing 62.5 L/min RMV at 198 fsw in 29 °F salt water) proved to be a poorly designed test for the Divator MK II scuba. Breathing at 62.5 L/min RMV and at 198 fsw was not always possible because of RE. In some cases the UBA could be breathed at 198 fsw; however, after the breathing simulator was stopped at depth to check for free flow, restarting the simulator at 62.5 L/min was not possible because the UBA's initial inhalation cracking pressure exceeded the unmanned breathing system instrumentation limits (7 kPa). In those cases, the breathing simulator was restarted at 50 L/min RMV to complete the dive. Two of five Divator MK II scuba UBAs with the positive-pressure FFM were able to complete the evaluation at an RMV of 62.5 L/min.

With the nonpositive-pressure FFM, one UBA could not be breathed at 198 fsw until the breathing rate was reduced to 40 L/min. One of the five Divator MK II scuba UBAs with the nonpositive-pressure FFM was able to complete the 198 fsw freeze-up evaluation at an RMV of 62.5 L/min.

Although no freeze-ups were exhibited during any of the 198 fsw freeze-up evaluations (with the positive-pressure or nonpositive-pressure FFMs) and because the 198 fsw freeze-up evaluations could not be completed at the breathing rate (62.5 L/min RMV) defined in the test plan, investigators decided to conduct the 130 fsw freeze-up evaluations.⁴

Scenario 8:

The Divator MK II scuba successfully completed the 130 fsw freeze-up evaluations in 29 °F salt water with both the positive- and nonpositive-pressure FFMs without freeze-ups.

CONCLUSIONS

RE Evaluations. At 38 °F the Interspiro DP2 surface-supplied UBA met the NEDU Technical Manual 01-94 RE goal of 1.76 kPa at 62.5 L/min for Category 2 UBAs to a depth of 198 fsw.⁵ This goal was met with both a 1500 and an 800 psig breathing gas supply pressure when both positive- and nonpositive-pressure FFMs were used.

At 29 °F the DP2 results with the positive-pressure FFM met the 1.76 kPa RE goal with a 1500 psig breathing gas supply to a depth 165 fsw. Although the RE met the goal to 198 fsw, the SD was 0.52 and therefore exceeded the allowable SD of 0.26. With the positive-pressure FFM the 1.76 kPa RE goal was also met with an 800 psig breathing gas supply pressure to a depth of 198 fsw.

At 29 °F with the nonpositive-pressure FFM and a 1500 psig breathing gas supply, the 1.76 kPa goal was also met to 198 fsw. With an 800 psig supply pressure the goal was not met at 62.5 L/min RMV at 198 fsw, but it was met at 40 L/min RMV.

With the exception of the Scenario 2 free-flow evaluation, all DP2 RE evaluations were conducted with the DP2 system configured with one simulated diver.

The Divator MK II scuba met the NEDU Technical Manual 01-94 goal of 1.37 kPa at 62.5 L/min RMV for Category 1 UBAs to a depth of 132 fsw.⁵ This goal was met in both 38 °F and 29 °F immersions with 1500 and 500 psig breathing gas supply pressures when both the Divator MK II positive- and nonpositive-pressure FFMs were used. This goal was also met to a depth of 165 fsw with a 1500 psig supply pressure and at 38 °F with the positive-pressure FFM.

Table 19.

This table summarizes the depths to which the NEDU Technical Manual 01-94 RE goals were met at 62.5 L/min for the Interspiro DP2 (1.76 kPa) and Divator MK II scuba (1.37 kPa) UBAs.

System	FFM	Supply Pressure (psig)	Depth (fsw) 29 °F	Depth (fsw) 38 °F
DP2	Positive-Pressure	800	198	198
		1500	165	198
	Nonpositive-Pressure	800	198*	198
		1500	198	198
MK II Scuba	Positive-Pressure	500	132	132
		1500	132	165
	Nonpositive-Pressure	500	132	132
		1500	132	132

*RE goal was met at 40 L/min but not at 62.5 L/min.

DP2 Free-flow Evaluation. This evaluation demonstrated that the RE of one FFM increases when the other FFM supplied from the DP2 free flows. When one positive-pressure FFM was supplied with 1500 psig breathing gas and breathed at 62.5 L/min RMV and the other was allowed to free flow, the Category 2 UBA goal of 1.76 kPa RE was met to 165 fsw. With an 800 psig breathing gas supply pressure, this goal was met to 99 fsw (sample size of n=1).

Freeze-up Evaluations. No contraindications to diving in 29 °F salt water were found during freeze-up evaluation dives with the Interspiro DP2 surface-supplied UBA or with the Divator MK II scuba when they were configured with either the positive- or the nonpositive-pressure Divator MK II FFM.

Equipment Discussion. During Interspiro evaluations, three of five high-pressure cylinder gauge assemblies flooded. This is evident in the water visible inside the case when the gauge pressure is read (Figure 15).

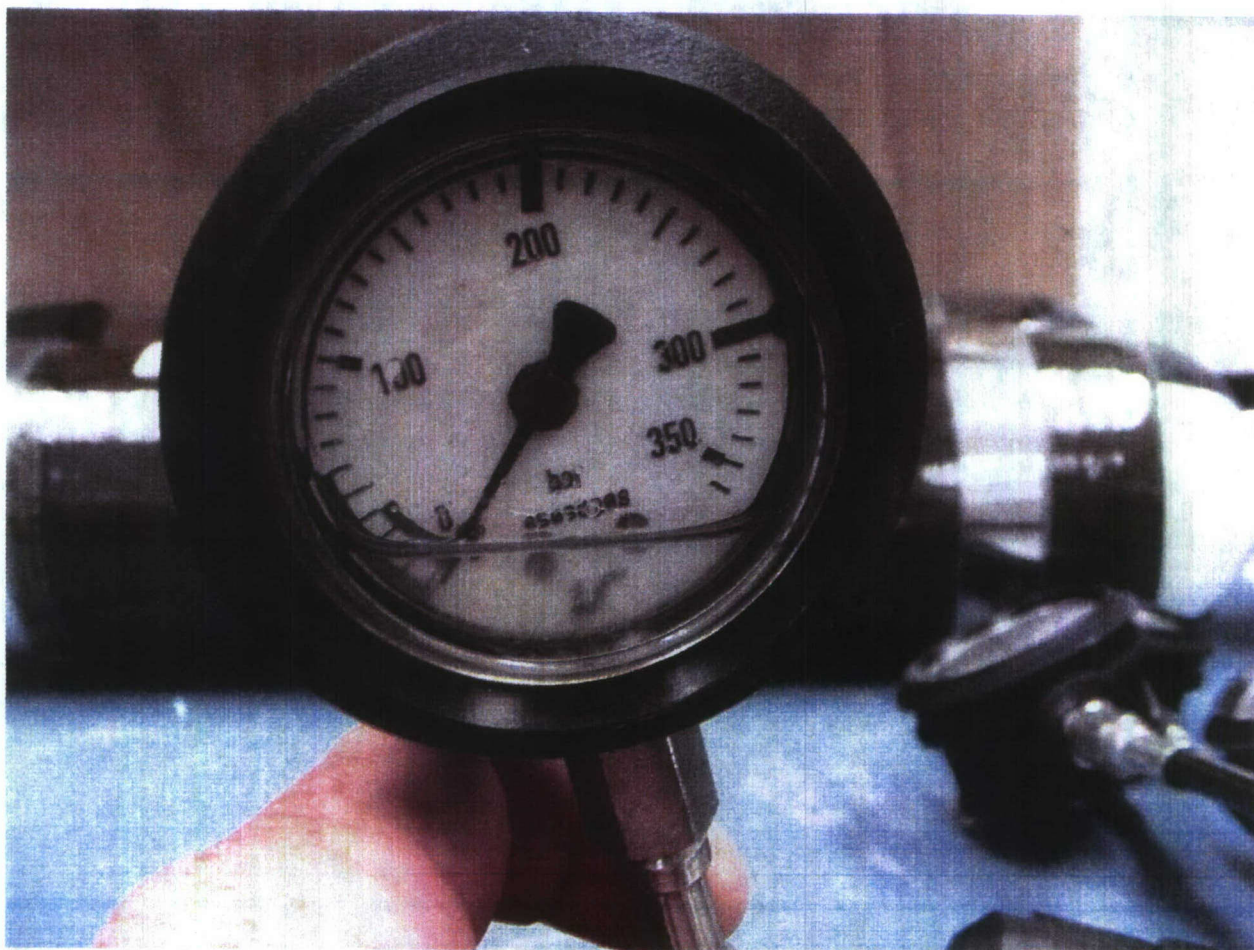


Figure 15. Interspiro high-pressure cylinder gauge showing flooding.

The Interspiro Spirolite high-pressure cylinders showed signs of salt retention in their outer coating. Cylinders used in salt water during unmanned evaluations were rinsed with fresh tap water after dive completion. Within a couple of days after the cylinders had been rinsed, salt began leeching from the outer coating (Figures 16–17). The significance (if any) of this salt retention is not known.

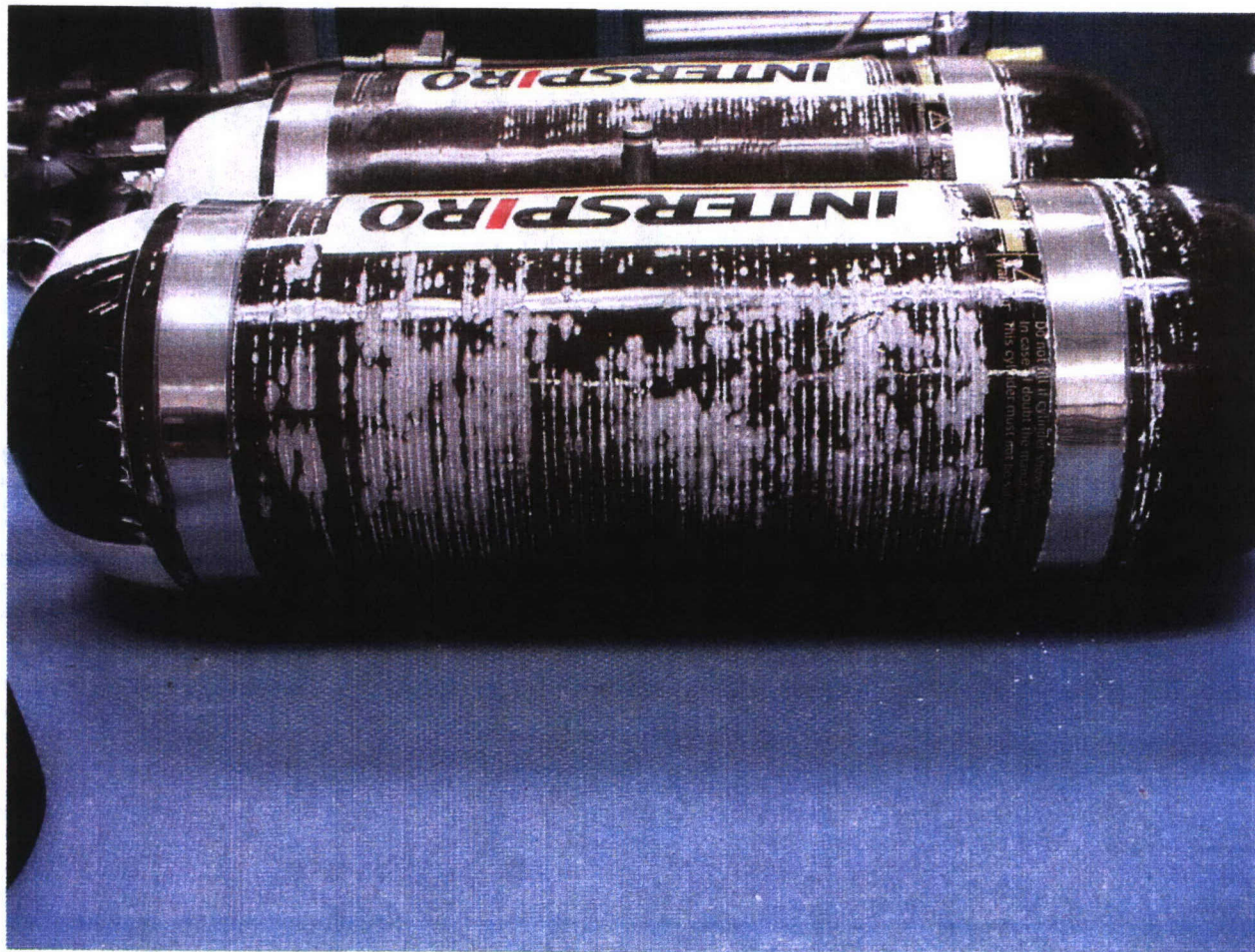


Figure 16. Interspiro Spirolite high-pressure cylinder showing salt leeching.

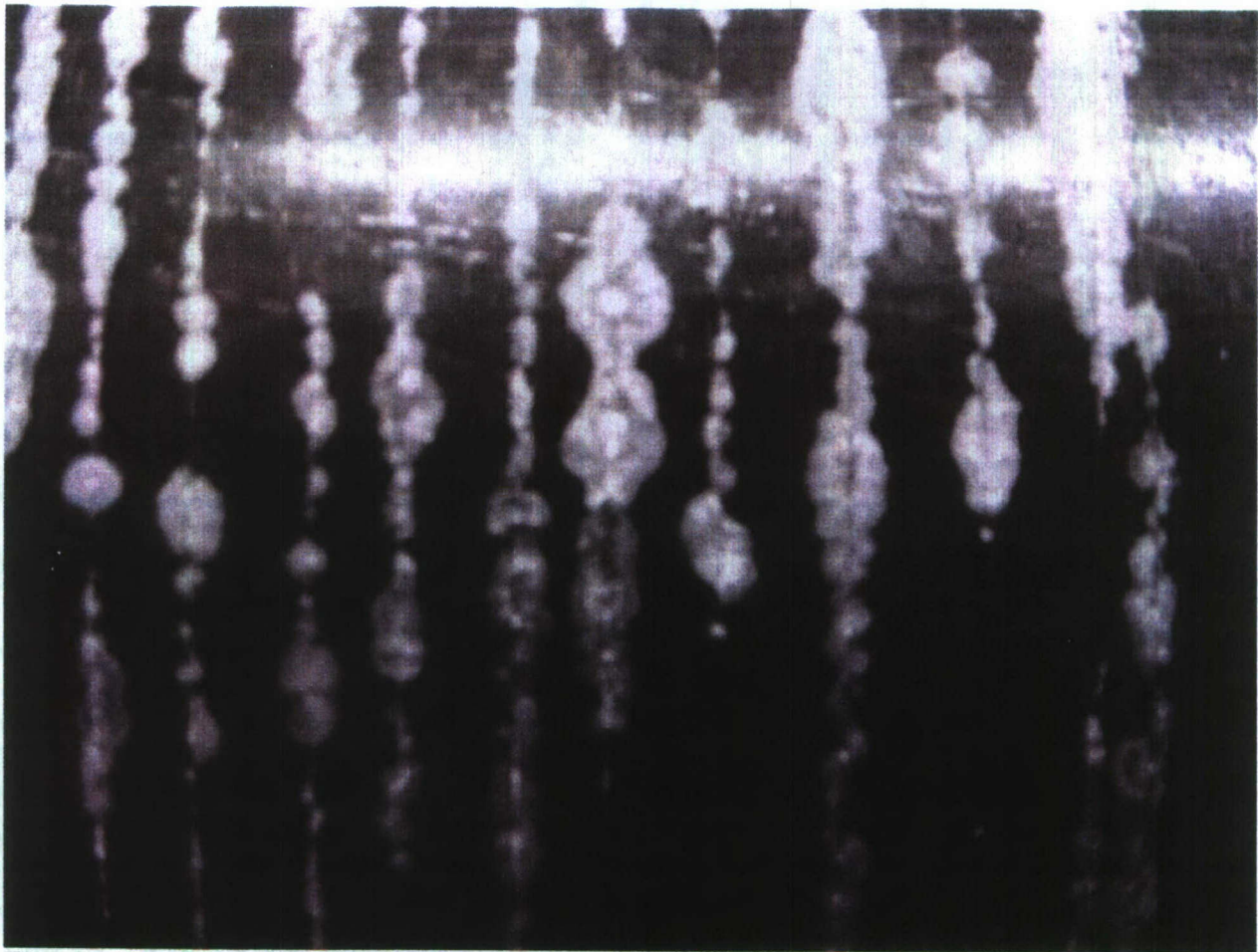


Figure 17. Close-up of Interspiro Spirolite high-pressure cylinder showing salt leeching.

RECOMMENDATIONS

To prevent flooding, the high-pressure cylinder gauges should be made more robust than at present. The salt retention and leeching from the Spirolite cylinder's outer coating should be investigated to determine what causes these conditions and what significance (if any) they represent.

From the results of unmanned testing, the Interspiro DP2 and Divator MK II UBAs have been found to be safe for manned evaluation in the NEDU test pool and OSF (Ocean Simulation Facility) in both freezing and nonfreezing water.

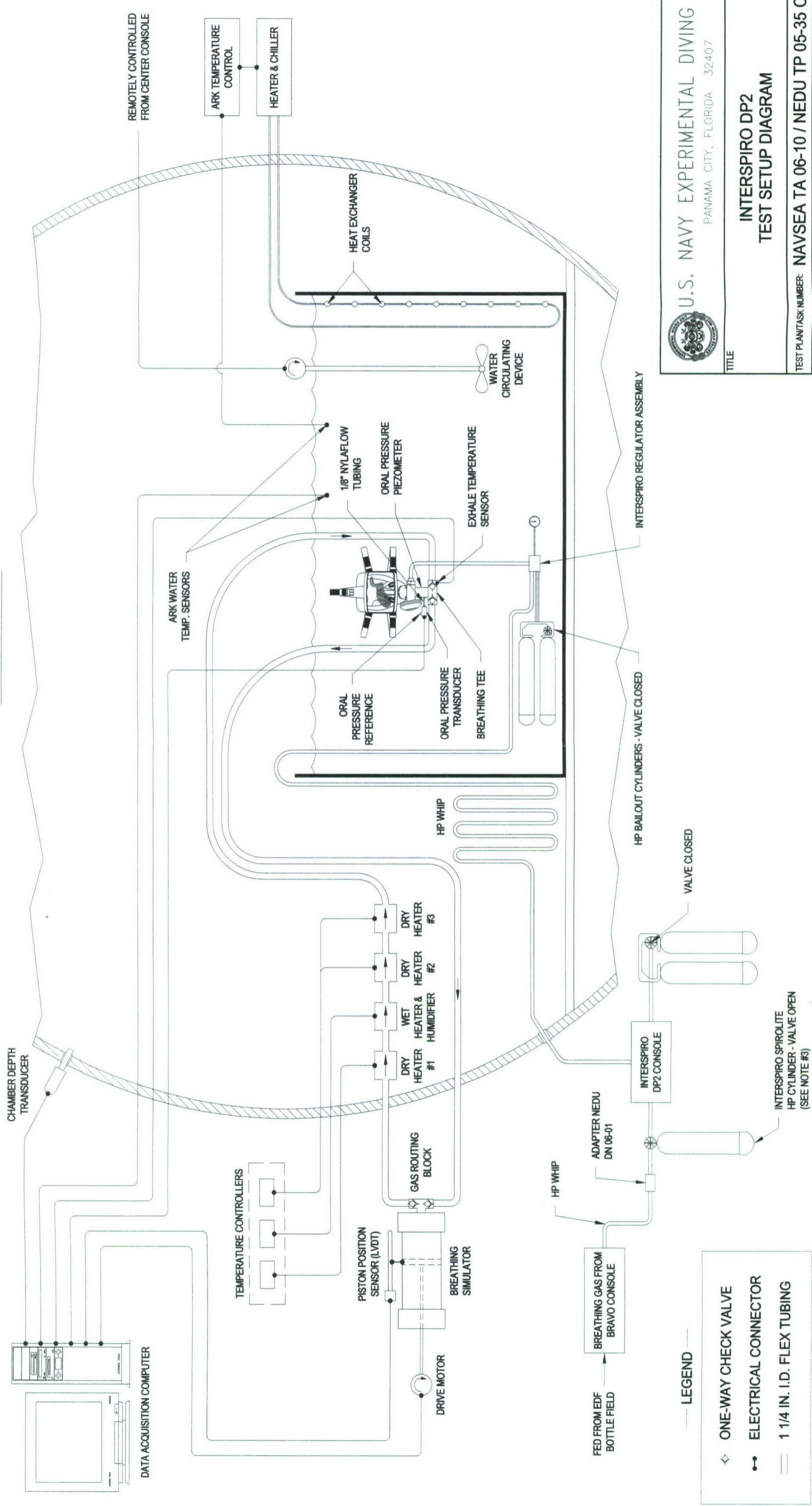
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NOTE:

1. HELMET MOUNTED ON MANNEQUIN HEAD (NOT SHOWN).
2. ORAL PRESSURE REFERENCE AT MANNEQUIN SUPRASNTERNAL NOTCH.
3. ONE CYLINDER REMOVED TO ACCOMMODATE HP WHIP ADAPTER (DN 06-01).

BRAVO CHAMBER



1. HELMET MOUNTED ON MANNEQUIN HEAD (NOT SHOWN).
2. ORAL PRESSURE REFERENCE AT MANNEQUIN SUPRASTERNAL NOTCH.
3. ONE CYLINDER REMOVED TO ACCOMMODATE HP WHIP ADAPTER (DN 06-01).

— LEGEND —

◇ ONE-WAY CHECK VALVE

● ELECTRICAL CONNECTOR

1 1/4 IN. I.D. FLEX TUBING



INTERSPIRO DIVATOR MK II SCUBA TEST SETUP DIAGRAM

APPENDIX A-2